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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Cracking Tests for Assessing Weldability

J. C. BORLAND: 'Cracking Tests for Assessing Weldability.'

Brit. Welding Jnl., 1960, vol. 7, Oct., pp. 623–37.

The author reviews the many types of cracking test which have been devised to assess weldability and discusses their characteristics, advantages and limitations. Details of each test are given in an appendix, and the paper includes a comprehensive bibliography.

The 30 tests described include those proposed for use in evaluating austenitic stainless steel.

NICKEL

Extraction and Refining of Nickel: Bibliography

MOND NICKEL COMPANY, LTD.: 'Extraction and Refining of Nickel, 1945–1960.'

Compiled by *The Technical Information Section* of *The Development and Research Department*, Sept. 1960; 84 pp. plus index.

The 234 items of this annotated bibliography cover virtually all the significant literature on the extraction and refining of nickel published over the period 1945–1960. A brief, but adequate, abstract indicates the scope of each reference, and full details are given of the original source.

A valuable feature of the bibliography is the provision of an index permitting ready reference to authors and subject matter.

Spectrographic Determination of Impurities in High-Purity Nickel Powder

S. HOUSELY, M. M. DIGGLE and G. A. PALMER: 'The Spectrographic Determination of Impurities in High-Purity Nickel Powder Using Nickel as Internal Standard.'

U.K. Atomic Energy Authority, Industrial Group Report SCS-R-158, July 19, 1950; 16 pp. Declassified 1959.

In considering the feasibility of applying available analytical techniques to the quantitative analysis of high-purity nickel powder, the authors rejected the iron-flux method as unsuitable, mainly on account of the loss of sensitivity resulting from dilution of the nickel with iron flux. A method was therefore required which would utilize the nickel itself as an internal standard and reduce the dilution of the sample to a minimum. General similarities in the chemical properties and spectra of iron and nickel having indicated that preliminary experiments could profitably be carried out using the iron-flux technique (suitably modified to cover the replacement of iron by nickel), it was considered necessary first to determine some means of making the pellet by which the nickel would be introduced into the arc, then to examine concentration and spectrographic conditions (with a view to obtaining a suitable nickel spectrum), and subsequently to introduce known amounts of impurities to establish the limits of detection. Finally, suitable standards for impurities were to be established and recoveries were to be investigated. Full details of the exploratory work involved are given in the present report. The method finally developed, the procedures employed (e.g., in the preparation of spectrographically pure nickel oxide, nickel flux and standard mixtures) and the results obtainable are described in appendices to the report.

In the method evolved the nickel powder is converted to nickel oxide by nitration and ignition. It is then mixed with ammonium sulphate, pelleted and spectrographed on copper electrodes in a direct-current arc. The impurities are estimated by comparing the sample spectra with those of standards containing added elements, using the nickel spectrum as internal standard. The concentration range covered is 0·001–0·2 per cent.

Spectrographic Analysis of High-Purity Nickel

R. L. RUPP, G. L. KLECAK and G. H. MORRISON: 'Spectrographic Analysis of High-Purity Nickel.'

Analytical Chemistry, 1960, vol. 32, July, pp. 931–3.

The rapid direct spectrographic method for the determination of trace impurities in high-purity nickel described by the authors was developed in connexion with research on the purification and fabrication processes used in the preparation of nickel components of electron tubes.

Chemical methods, although generally employed for the determination of trace impurities in nickel,

require large samples, are time-consuming and may involve contamination by reagents. A direct spectrographic method capable of simultaneously determining many impurities in samples of limited size was preferred, but the methods available were suitable for determinations only at concentrations down to 40 p.p.m. In the procedures considered, which were based on a total-burn method in air, the sample was completely burned in a spectrographic arc to ensure total volatilization of impurities into the arc stream. The simultaneous volatilization and excitation of the matrix material over the entire period of arcing contributed heavily to the background on the photographic emulsion, so that the spectral lines of the impurity elements were heavily masked. When, however, the arcing was performed under less rigorous conditions (achieved by use of argon or nitrogen atmospheres), it was found possible greatly to increase spectrographic sensitivity: the method described, based on this finding, is applicable to determination of impurities in the range 0·1–100 p.p.m.

ELECTRODEPOSITION AND OTHER COATING METHODS

Electrodeposition of Nickel-Zinc-Alloy Corrosion-Resistant Coatings: Specification

SOC. AUTOMOTIVE ENGINEERS: 'Nickel-Zinc Alloy Plating.'

Aeronautical Material Specification 2417, issued June 30, 1960; 3 pp.

The nickel-zinc-alloy coatings to which the specification relates are electrodeposited onto steel components as a means of conferring corrosion-resistance at service temperatures up to 900°F. (480°C.). No post-plating diffusion treatment is required.

The alloy, the nickel content of which should be between 16 and 30 per cent., is deposited, over a nickel strike, from a nickel-chloride/zinc-chloride/acetic-acid solution containing no addition agents which might be deleterious to deposit or basis metal. The thickness of the nickel strike should be 0·00005 in. (0·00125 mm.) minimum, and where the surface may be touched by a ¼-in.-diameter sphere, the thickness of the alloy deposit should (with the exception of washers or components with an external thread, which should be coated with an alloy deposit 0·0002–0·0004 in. (0·005–0·01 mm.) thick) be 0·0003–0·0007 in. (0·0075–0·0175 mm.).

Test panels plated to thicknesses of 0·0002–0·0004 in. should show no visual evidence of basis-metal corrosion after exposure for 48 hours to the salt-spray corrosion test. The post-plating hydrogen-embrittlement-relief treatments specified vary with the hardness of the plated steel.

Levelling in Bright-Nickel-Plating Solutions

S. E. BEACOM and B. J. RILEY: 'Further Studies of Levelling Using Radiotracer Techniques.'

Jnl. Electrochemical Soc., 1960, vol. 107, Sept., pp. 785–7.

In a previous paper the authors demonstrated, using radiotracer techniques, that the organic addition agent, sodium allyl sulphonate, which imparts levelling characteristics to a bright-nickel-plating solution, is preferentially adsorbed onto the peaks of an irregular surface, a finding which was regarded as verification of a theory of levelling which assumes that the process is initiated by such preferential adsorption.

The cathodes employed were machined to provide a surface of alternate peaks and valleys, and the peak-to-peak separations (0·16 cm.) and peak-to-valley heights (0·077 cm.) were rather large. It seemed important to determine the limit to which this concept of preferential adsorption could be extended, and, in the investigation described, a series of machined cathodes of decreasing surface roughness were therefore prepared and plated in nickel-plating solutions containing the addition agent tagged with S-35. Within the limits of the techniques available, the results show that the concept of preferential adsorption may be extended to include those surfaces which more nearly approach a microprofile dimension.

To establish further the reliability of the results reported, it was considered desirable to show that the radioactivity observed in the deposits came only from the S-35 isotope and not from some other radioactive impurity. It appeared also of value to show, by an exchange study, that the observed activity comes directly from the sulphonate part of the tagged addition agent and not indirectly by way of an exchange with the sulphate ions present in the plating solution. The results obtained confirm that the observed activity was indeed due to the presence of pure S-35, and that it came directly from the sulphonate group.

(See also, in connexion with this paper, that by ROGERS *et al.* reporting work in the same field: abstract in *Nickel Bulletin*, 1960, vol. 33, No. 10, pp. 237–8.)

Bridged Complexes and the Deposition of Tin-Nickel Alloys

R. L. RAU and J. C. BAILAR: 'Bridged Complexes and the Deposition of Tin–Nickel Alloys.'

Jnl. Electrochemical Soc., 1960, vol. 107, Sept., pp. 745–8.

Since the introduction of bright tin-nickel plating, much interest has been aroused in the nature of the species responsible for the virtually constant 1/1 atomic ratio of tin/nickel in the deposit. In order to explain the constancy of composition obtained over a wide range of conditions, several investigators have postulated the existence of a tin-nickel complex. In spite of the reluctance of nickel (II) to form fluoride complexes, some combination of $SnF_4^=$ with nickel (II) seems to occur, though conclusive evidence for this has not been established. In the

experiments now reported, the method of continuous variations was used to determine the nature of the complex in solutions containing tin (II), nickel (II), and fluoride ions.

The results of the study indicate the formation of $SnF_4^{=}$, which, in turn, forms $NiSnF_4$. Other complexes of the type $NiSnF_x^{4-x}$ (where x is 1, 2 or 3) have also been shown to exist. These complexes may contain one or more fluoride bridges. There was no indication of complex formation in the absence of fluoride.

Plating of Buffed Zinc-base Die Castings

N. ANANIATIS: 'Practical Observations on Plating Buffed Zinc Die Castings.'

Plating, 1960, vol. 47, Sept., pp. 1023–6.

The article, which is based on the author's practical experience in decorative plating of zinc-base die castings, draws attention to the factors (beneficial or adverse) of significance in production plating, and to the plating procedures which he has found effective.

These subjects are discussed in sections covering: pricing estimates; plating racks; surface defects; pre-plating operations; copper plating; nickel plating; chromium plating.

Deposition and Protective Value of Microcracked Chromium

W. H. SAFRANEK and R. W. HARDY: 'Use of Selenic Acid for Plating Microcracked, Protective and Decorative Chromium Plate.'

Plating, 1960, vol. 47, Sept., pp. 1027–31.

Previous investigations having demonstrated the feasibility of obtaining bright microcracked chromium deposits from a solution (operated at 110°–112°F.: 43°–44°C.) containing chromic acid 250, sulphuric acid 2·5, selenic acid 0·007–0·02, g./L., the study reported in the present paper was undertaken to determine the value of these deposits as protective coatings.

It was found possible, by varying the selenic acid within the above range, to produce chromium deposits exhibiting one of three different crack-structure systems: (1) a system of closely-spaced continuous microcracks; (2) a system of discontinuous microcracks; (3) a system of non-uniform microcracks.

Die-cast panels, plated with 0·4 mil of copper, 0·8 mil of bright-nickel and 0·05–0·06 mil of microcracked chromium exhibiting a continuous or non-uniform system of microcracks were subjected to the copper-accelerated salt-spray test. No basis-metal corrosion occurred during an exposure period of 144 hours, and the results obtained indicate that the protection conferred on the basis metal by composite coatings incorporating such microcracked chromium deposits is superior to that associated with copper/nickel/chromium coatings incorporating a similar thickness of conventional chromium. The data available indicate also that the corrosion performance of the microcracked chromium deposited from a selenic-acid-containing solution compares favourably with that of microcracked chromium deposited commercially by a two-step process.

NON-FERROUS ALLOYS

Factors Influencing Fusion-Line Cracking of Welded Cupro-Nickels

C. E. WITHERELL: 'Some Factors Affecting the Weldability of the Cupro-Nickels.'

Welding Jnl., 1960, vol. 39, Sept., pp. 411s–16s.

The cupro-nickel alloys, like most other commonly welded materials, are not free from welding problems, and the factors contributing to fusion-line cracking, the source of most of the welding difficulties encountered with these alloys, formed the subjects of the investigation now described. Previous investigations had indicated that phosphorus has an adverse effect on the weldability of cupro-nickel, though in no case has there been conclusive evidence that fusion-line cracking is the result of a high phosphorus content alone. It seemed reasonable to assume that if phosphorus were detrimental to weldability, other elements too might have a similar effect, an assumption which was verified by preliminary tests on cupro-nickel alloys containing single additions of such elements as lead, bismuth and sulphur. On the basis of this finding, an extensive programme was initiated to evaluate the effects of single additions of most of the more common elements reputed to contribute, either directly or indirectly, to hot shortness in copper or nickel alloys.

The tee-joint fillet-weld specimen was selected as a suitable means of determining susceptibility to fusion-line cracking, and three types of filler material were employed in the tests: nickel, 70–30 nickel–copper alloy, 70–30 copper–nickel alloy. Most of the welding was carried out by the inert-gas-shielded metal-arc process though some welds were produced using nickel or 70–30 copper-nickel-alloy covered electrodes. Cupro-nickels of 70–30 or 90–10 type served as basis materials. The influence of the following factors was studied: trace elements; filler-metal composition; welding process; restraint; condition of the basis plate material (as-cold-rolled or annealed).

A table listing the maximum amounts of the various trace elements which could be tolerated in 70–30 and 90–10 cupro-nickel basis metals before occurrence of fusion-line cracking is reproduced on p. 274. These data, and the findings of the other phases of the investigation, lead the authors to conclude that fusion-line cracking is primarily the result of low-melting-point segregates which form at the weld interface in the presence of sufficient amounts of certain trace elements or impurities. Cracking appeared to occur when the stresses generated by the cooling mass of weld metal exceeded the strength of the low-melting-point segregates, and trace elements having a low solubility in, or forming low-melting-point eutectics with, copper are considered chiefly responsible. Welding conditions promoting rapid cooling rates and rapid solidification of the deposited weld metal, or the use of nickel or a high-nickel nickel–copper alloy as filler metal, tended to favour the segregation of the low-melting-point constituents and, thereby, to increase the likelihood of fusion-line cracking.

Tolerable Limits for Individual Trace Elements in 70-30 and 90-10 Cupro-Nickels*

(*See abstract on p. 273*)

	Element	Maximum Content Evaluated %	Maximum Amount tolerated when using 70-30 copper-nickel filler %	Maximum Amount tolerated when using nickel filler (See Note 1) %	Comments
70–30 Cupro-Nickel	Silver	0·08	†	†	—
	Arsenic	0·07	†	†	—
	Boron	0·06	†	0·02	See Note 2
	Beryllium	0·03	†	†	—
	Bismuth	0·003	†	0·002	—
	Carbon	0·20‡	†	†	See Note 3
	Cadmium	<0·01§	†	†	—
	Phosphorus	0·06	0·02	0·01	—
	Lead	0·07	0·05	0·01	—
	Sulphur	0·09	†	0·06	—
	Antimony	0·11	†	†	—
	Selenium	0·05	†	0·02	—
	Silicon	0·9	†	0·8	—
	Tin	0·6	†	†	—
	Tellurium	0·65	0·02	0·01	—
	Zinc	0·9	†	†	—
90–10 Cupro-Nickel	Silver	0·08	†	†	—
	Boron	0·05	†	0·02	See Note 2
	Bismuth	0·01	0·008	0·005	—
	Cadmium	0·02	0·02	0·01	—
	Phosphorus	0·07	0·02	0·02	—
	Lead	0·07	0·02	0·02	—
	Sulphur	0·09	†	0·08	—
	Antimony	0·08	†	0·05	—
	Selenium	0·08	0·03	0·02	—
	Tin	0·8	†	†	—
	Tellurium	0·07	0·02	0·005	—

*With all other impurities and trace elements kept at lowest possible level.

†No threshold established; no fusion-line cracking observed in material having content shown under 'maximum content evaluated'.

‡Including free graphite.

§Cadmium recoveries found to be very poor in 70-30 cupro-nickel.

NOTES:

(1) This filler does not offer optimum welding response in welding 70-30 or 90-10 cupro-nickels, and is shown for purposes of information and comparison only.

(2) Although no fusion-line cracking occurred in welds made using 70-30 filler and 70-30 or 90-10 plate (containing, respectively, up to 0·06 and up to 0·05 per cent. boron), weld-metal cracking was observed in welds made in plate having greater than about 0·03 per cent. boron.

(3) No detrimental effect noted to limit of solid solubility.

Thermal Conductivity of 70-30 Cupro-Nickel at 0·3°–4·0°K.

H. A. FAIRBANK and D. M. LEE: 'Thermal Conductivity of 70–30 Cupro-Nickel Alloy from 0·3° to 4·0°K.'

Rev. Scientific Instruments, 1960, vol. 31, June, pp. 660–1.

During measurement of the heat-transport properties of liquid helium, the thermal conductivity of a cupro-nickel alloy containing copper 69·6, nickel 30, iron 0·4, per cent., was determined from 0·3° to 4·0°K. The alloy was drawn into tube and, after the last anneal, was subjected to a 30 per cent. reduction and designated 'half-hard'.

The results, presented in a log./log. plot, can, it is stated, be represented satisfactorily by the equation

$$K = 0{\cdot}93 \times 10^{-3} T^{1{\cdot}23},$$

where K is in w./cm.°K. and T is in °K.

CAST IRON

Second-Stage Graphitization in Nickel-containing S.G. Iron

J. BURKE: 'Second-Stage Graphitization in a Nodular Cast Iron.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Sept., pp. 42–5.

Under equilibrium conditions at room temperature most cast irons consist of graphite and ferrite, a structure which is formed in two stages: first- and second-stage graphitization. In second-stage graphitization, precipitation can occur directly from austenite during cooling, or, alternatively, the austenite can first transform to pearlite, bainite or martensite, which subsequently can be decomposed to graphite and ferrite by annealing below the eutectoid temperature. The graphitization of pearlite and austenite normally proceeds by the further growth of the primary graphite, whereas the decomposition of martensite results in the formation of a new generation of nodules. This latter observation is surprizing, since it implies the existence of sites which nucleate graphite more effectively than graphite itself. In the work described, carried out to throw light on this problem, a study was made of the kinetic and structural features of the graphitization of pearlite and martensite in a spheroidal-graphite cast iron

produced by the standard process of treatment with nickel-magnesium alloy and ferrosilicon (and containing carbon 3·3, silicon 2·5, nickel 2, per cent.).

Isothermal secondary graphitization was studied as a function of initial structure (pearlitic or martensitic) at 670°, 690° and 710°C., using standard dilatometric and metallographic techniques.

The decomposition of martensite invariably resulted in the formation of new nodules of graphite, and a similar structure was observed occasionally also in samples initially pearlitic. The graphitization of pearlite, however, more often produced secondary graphite in the form of a deposit upon the primary nodules. The kinetic features indicate that (1) before the primary nodules are capable of further growth at temperatures below the eutectoid, a time-dependent nucleation process is necessary, and (2) the rate of growth of graphite is diffusion-controlled.

CONSTRUCTIONAL STEELS

Nickel-containing Low-Alloy Steels: Specifications

The *Aeronautical Material Specifications* referred to below were recently issued by the SOCIETY OF AUTOMOTIVE ENGINEERS. They lay down requirements with respect to: forms and condition in which the steel is to be supplied; applications; composition; technical properties; quality; tolerances; reports of test results; identification; rejections. The limits of composition specified for the four steels covered are tabulated on p. 281. The forms available and the main applications are noted below.

'Steel, Premium-Quality, 3·25Ni-1·2Cr-0·1Mo (0·07-0·13C)-(SAE 9310), Consumable-Electrode Vacuum-Melted.'

Aeronautical Material Specification 6265, issued June 30, 1960; 3 pp.

The steel (in the form of bars, forgings, forging stock and mechanical tubing) is intended 'primarily for critical carburized parts requiring high minimum core hardness with narrow range, and where very rigid magnetic particle inspection standards are utilized in final inspection'.

'Steel, Premium-Quality, 0·55Ni-0·5Cr-0·2Mo (0·18-0·23C)-(SAE 8620), Consumable-Electrode Vacuum-Melted.'

Aeronautical Material Specification 6276, issued June 30, 1960; 3 pp.

Bars, forgings, forging stock and mechanical tubing in the steel covered are intended for the same principal application as those covered by *A.M.S.* 6265. The core may or may not be machinable after hardening.

'Steel, 1·8Ni-0·8Cr-0·35Mo-0·2V (0·33-0·38C), Vacuum-Melted.'

Aeronautical Material Specification 6429, issued June 30, 1960; 4 pp.

The steel is a weldable grade, principally for use in heat-treated parts which require through-hardening to high strength levels and which may be employed at operational stress levels approaching the yield strength. It is supplied in the form of bars, forgings, forging stock and mechanical tubing.

The material may be notch-sensitive when heat-treated to a minimum tensile strength of 240,000 p.s.i. (107 t.s.i.:168·5 kg./mm.^{2}), and caution is advised in this respect.

'Steel, Sheet and Strip, 1·8Ni-0·8Cr-0·35Mo-0·2V (0·33-0·38C), Vacuum-Melted.'

Aeronautical Material Specification 6435, issued June 30, 1960; 4 pp.

The steel is intended for the same applications as that covered by *A.M.S.* 6429. It is, however, to be supplied in sheet, strip or plate form.

Determination of Chromium in Nickel-containing Steels

See abstract on p. 278.

Influence of Composition on the Structure and Properties of Martensite

K. J. IRVINE, F. B. PICKERING and J. GARSTONE: 'The Effect of Composition on the Structure and Properties of Martensite.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Sept., pp. 66-81.

Since the commonest method of achieving a high level of tensile strength in a structural steel is to quench (to produce martensite) and temper (to ensure adequate ductility), the properties of martensite are of considerable interest. In the work described these properties were studied, as a function of composition, in plain-carbon and low-alloy steels in the as-quenched condition or after light tempering (i.e., in the range 100°-300°C.).

In the plain-carbon steel, carbon contents were varied up to a maximum of 0·9 per cent. The influence of alloying elements was investigated in relation to steels (of 0·5 manganese-0·2 silicon basis composition) containing up to 0·8 per cent. carbon and up to 4 per cent. of either manganese, nickel, chromium or molybdenum. The mechanical properties of commercial steels of the following types (containing 0·29-0·5 per cent. carbon, and oil-quenched and then tempered at 200°C.) were correlated with their microstructure: 1% Cr; 1% Cr-0·3% Mo; 3% Cr-½% Mo; 1½% Ni-1¼% Cr; 1½% Ni-1·2% Cr-0·25% Mo.

From the data presented the authors conclude that the amount of carbon in solid solution is the major

factor controlling the hardness and strength of martensite. Although, compared with polygonal ferrite, the fine grain-size of the structure does result in an increase in strength, grain-size does not vary with rise in carbon content, and its effect is therefore relatively small in high-carbon steel. If grain-size can, however, be reduced (e.g., by warm working before martensite transformation), strength can be appreciably increased.

Alloying elements have little effect on martensite structure and mainly influence the tempering process, retarding carbide precipitation and maintaining the high martensitic hardness at higher temperatures. In low-carbon steels, an alloying element may reduce auto-tempering, and, hence, significantly increase hardness, but, in general, the effect of such an addition is relatively small.

The mechanical properties of plain-carbon martensite are optimum at carbon contents of 0·3–0·5 per cent., and after tempering at 200°–300°C. Alloy steels at any particular strength level exhibit higher ductility and impact properties than plain-carbon steels, particularly when molybdenum is present, an effect which, it is suggested, appears to be due to a modification of carbide precipitation involving elimination of films at martensite plate boundaries.

Influence of Inclusions on the Fatigue Properties of Steel

J. WATANABE: 'Some Observations on the Effect of Inclusions on the Fatigue Properties of Steels.'

Proc. 3rd Japan Congress on Testing Materials, 1960, pp. 5–8.

Published by *Japan Soc. for Testing Materials.*

In this paper the author presents, and discusses, the results of a study of the relationships between the fatigue properties, inclusion content and tensile properties of low-alloy steels.

The tensile and rotating-bend fatigue specimens tested were taken (in the transverse and longitudinal directions) from the journal portions of five large turbo-generator rotor-shaft forgings, two in 3-0·6-0·4-0·1 nickel - chromium - molybdenum - vanadium steel, the remainder fabricated from 3-0·4-0·1 nickel-molybdenum-vanadium steel. One heat of each grade was vacuum poured from the basic electric-arc furnace; all the others were produced in the acid open-hearth furnace. Both smooth and notched fatigue specimens were evaluated, and the inclusion content, and the type and dimensions of the inclusions present, were determined (by methods described in the paper).

All the inclusions present were found to be elongated and of the silicate or sulphide type. The data show that, of these two types, the silicate has the more deleterious effect on transverse fatigue properties (a finding which was supported by the results of the tensile tests which indicated that the silicate was the more powerful stress raiser). At the levels of strength and forging ratio studied, sulphide inclusions influenced fatigue properties by less than 10 per cent., even at relatively high sulphide contents. The vacuum-poured electric-arc-furnace heats exhibited good cleanliness and fatigue properties. Notch fatigue strength showed little anisotropy.

Steels for the Containment of Liquefied-Gas Cargoes

W. S. MOUNCE, J. W. CROSSETT, T. N. ARMSTRONG: 'Steels for the Containment of Liquefied-Gas Cargoes.' *Trans. Soc. Naval Architects*, 1959, vol. 67, pp. 423–38; *disc.*, pp. 438–48.

Materials which are in the gaseous state at atmospheric temperature and pressure play an essential rôle in present-day technology, and production facilities are being constantly increased to provide adequate supplies. The degree to which the range of application of these materials will continue to expand depends to some extent on the provision of an economical means of transportation and storage, a fact which has resulted in a growing interest in the handling of normally gaseous materials in their liquid state: at atmospheric pressure, the gas-volume/liquid-volume ratio ranges from 316/1 for propane, to 850/1 for hydrogen and oxygen, and the savings achieved in container space are obvious. To maintain a gas in liquid form at atmospheric pressure, the temperature of the liquid must be held below the boiling point, and since the boiling temperatures of, for example, propane and helium are, respectively, —43·7°F. and —452°F. (—42°C. and —269°C.), the designer of equipment to store and transport liquefied gases must overcome the problems associated with low temperatures. He can, however, draw on the considerable background of experience gained in the industrial-gas-producing and the process industries, where pressure vessels and processing equipment have been used at these low temperatures for some years. In this paper the authors refer to experience with, and data available on, relevant low-temperature steels, and discuss the problems involved in low-temperature service in the particular light of the suitability of such steels for use in the marine transportation of liquefied gases.

Four grades of steel are considered: Type 304 chromium-nickel stainless steel, and 2¼, 3½ and 9 per cent. nickel steels. In the main body of the paper, attention is drawn to the more commonly liquefied gases and to the tankers which have already been built for their transportation. Experience with pressure vessels operating at low temperature is noted, the problem of brittle fracture is referred to, and properties significant to assessment of the suitability of steels for low-temperature service are reviewed. Reference is made to the results of fracture tests on cylindrical prototype tanks (fabricated, by welding, from stainless steel and 9 per cent. nickel steel and filled with liquid nitrogen at —320°F. (—196°C.)), and to proposed tests designed to demonstrate further the suitability of 9 per cent. nickel steel for use in tanks containing liquids at such temperatures.

A.S.T.M. Specifications have laid down arbitrary

limits with respect to the lowest service temperature permissible for the 2¼, 3½ and 9 per cent. nickel steels (—75°, —150° and —320°F. (—60°, —100° and —195°C.), respectively). In appendices to the paper the authors present design data sheets alluding to the standard specifications covering relevant stainless steels and the three nickel steels, and including information on pressure-vessel design stresses, fatigue properties, low-temperature notch-toughness, weldability, thermal expansion, thermal conductivity and specific heat.

See also

9 per cent. Nickel Steel for Low-Temperature Service

R. J. JOHNSON: 'Nickel Steel Alloys for Liquids at —320°F.: 9 per cent. Excels.'

Chemical Engineering, 1960, vol. 67, July 25, pp. 115–8.

Low-carbon 9 per cent. nickel steel was developed to provide a moderately priced steel for use in equipment handling or storing liquefied gases at temperatures down to —320°F. (—196°C.). Activity in the field of cryogenics is increasing, parallel with increase in, for example, the demand for oxygen in steel making, ore roasting, and missile propulsion. Much work is being carried out on marine transportation of liquefied gases (*see preceding abstract*), and a prototype ship is already delivering liquid methane at —260°F. (—160°C.) to the United Kingdom: such tankers, and their land-based storage facilities, are expected to be large consumers of 9 per cent. nickel steel. The suitability of this grade of steel for low-temperature applications forms the subject of the present article. (The steel is covered by *A.S.T.M. Specifications A*-300 and *A*-353, which require that the steel exhibit a notch impact strength of 15 ft.-lb. (2·07 kgm.) at a minimum temperature of −320°F. (−196°C.).)

In the paper the authors present information and data on: heat-treatment; low-temperature impact properties obtainable in plate; fatigue properties; welding characteristics; properties of weldments; applications; and cost considerations. Reference is made to those sections of the *A.S.M.E. Boiler and Pressure Vessel Codes* relevant to 9 per cent. nickel steel.

See also

Low-Alloy Nickel Steels for Low-Temperature Service

R. ROTE and J. H. PROCTOR: 'A-300 Alloy Steels Serve the —50°F. to —150°F. Range.'

Chemical Engineering, 1960, vol. 67, June 27, pp. 119–22.

Parallel with the tremendous expansion in the production of cryogenic liquids (e.g., oxygen, hydrogen and nitrogen), the last decade has seen interest increase in certain liquids that are manufactured and handled at more moderate, but, nevertheless, low, process temperatures (e.g., ethylene). Materials which resist brittle fracture at low atmospheric temperatures, as, for example, obtain in Arctic service, have also been the subjects of growing interest. The use of certain steels in this less severe temperature range (—50°F. to —150°F.: —46°C. to —100°C.) is well established, and their fabrication and properties are covered by specifications set up by the A.S.T.M. and A.S.M.E. Unfired Pressure Vessel Code Committees. For pressure-vessel work the *A*-300 classification was inaugurated to cover carbon and alloy steels for use at temperatures down to —150°F. (—100°C.). A considerable number of steels are produced to this classification, including the *A*-201 and *A*-212 grades (specially-treated carbon steels for service down to −50°F. (−45°C.)), the alloy steels conforming to *A*-203 *Grade A* or *B* (2¼ per cent. nickel steel) for service down to −75°F. (−59°C.), and those covered by *A*-203 *Grade D* or *E* (3½ per cent. nickel steel) for service down to −150°F. (−100°C.). *A*-410, a chromium-copper-nickel alloy steel for service down to −150°F. (−100°C.), is not widely used. For applications requiring high strength in combination with satisfactory low-temperature properties, the nickel-chromium-molybdenum-vanadium steel 'T-1' (not specified under *A*-300) is finding increasing use.

In this paper the authors outline the advantages offered in low-temperature applications by 'T-1' and the *A*-300 alloy steels. They summarize relevant properties and briefly draw attention to design and cost considerations.

See also

Stainless Steels for Low-Temperature Service

J. H. MCCONNELL and R. R. BRADY: 'Austenitic Stainless Steels: Thousands of Tons in —300°F. to —425°F. Service.'

Chemical Engineering, 1960, vol. 67, July 11, pp. 125–8.

In introducing their subject, the authors refer to the suitability of the chromium-nickel stainless steels for service at temperatures in the range —300° to —425°F. (—185° to —255°C.), and cite, as evidence, the thousands of tons of stainless steel used in the production and storage of liquid oxygen (one investigator found that after 15 years' exposure to liquid oxygen a Type 303 18–8 valve stem still exhibited an impact strength of 15 ft.-lb. at —295°F. (—180°C.)). Type 304 stainless steel is used extensively in the construction of storage tanks for liquid oxygen, nitrogen and helium, as well as for the auxiliary piping, at many intercontinental ballistic missile installations. The initial cost of stainless steel may be somewhat higher than that of other materials, but this expenditure is, in the authors' opinion, compensated by ease of fabrication and welding, combined with high strength and excellent shock-resistance. These advantages are regarded as an economic justification for the use of stainless steels in cryogenic applications at temperatures down to —425°F. (—255°C.).

In the main part of the paper the authors review the relevant properties of the five grades of stainless steel generally employed for sub-zero service: A.I.S.I. Types 302, 304, 304L, 310 and 347 (i.e., 18–8, 19–10,

extra-low-carbon 19-10, 25-20 and 18-11-Nb chromium-nickel steels). Data are presented to illustrate notch-toughness, tensile properties, coefficient of expansion, and modulus of elasticity at sub-zero temperatures. Sensitization (precipitation of chromium carbides at the grain boundaries which may occur in the heat-affected zones of some stainless steels after welding) is discussed in relation to its effect on impact properties: illustrative data are presented on the impact properties of sensitized or annealed specimens of pertinent grades of stainless steel and on weld metal in the as-cast and annealed conditions.

Corrosion Behaviour of Architectural Steels in Canadian Atmospheres

See abstract on p. 284.

Development of a Non-Embrittling Cadmium-plating Process for High-Strength Steels

S. W. STRAUSS and P. N. VLANNES: 'Progress Toward the Development of a Non-embrittling Cadmium Electroplating Process. V. The Use of Pyridine as a Complexing Agent in Cadmium-Plating Solutions.'
Plating, 1960, vol. 47, Sept., pp. 1037-9.

In previous work concerned with their search for a non-cyanide cadmium-plating solution which would not embrittle ultra-high-strength-steels, the authors had used amino acids and triethanolamine as complexing agents in aqueous cadmium solutions (see abstracts in *Nickel Bulletin*, 1959, vol. 32, No. 11, p. 327; 1960, vol. 33, No. 1, p. 13). In the present paper, details are given of the results obtained using the cyclic tertiary amine, pyridine, as the complexing agent.

A study was made of current-density characteristics, current efficiency, throwing power, and continuous-plating characteristics. The current efficiency of the cadmium/pyridine solution approached 100 per cent., and the throwing power was similar to that of the cyanide solution at small distance ratios of far-to-near cathode. The results of delayed-fracture tests on notched specimens of A.I.S.I. 4340 nickel-chromium-molybdenum low-alloy steel heat-treated to high strength levels indicated that the solution is not embrittling.

Cracking Tests for Assessing Weldability

See abstract on p. 271.

Weldability of Ultra-High-Strength Steels

M. J. ALBOM and C. C. TITHERINGTON: 'Investigation of Weldability of Ultra-High-Strength Steels.'
Welding Jnl., 1960, vol. 39, Sept., pp. 385s-91s.

In an attempt to produce full-penetration welds meeting a minimum yield-strength requirement of 220 kg./in.^{2}, specimens of four ultra-high-strength steels (two of which were 5 per cent. chromium-molybdenum-vanadium hot-work die steels, one a 5 per cent. chromium-nickel-molybdenum-vanadium hot-work die steel, and the fourth a high-silicon chromium-molybdenum-vanadium low-alloy steel) were welded by the automatic inert-gas-shielded tungsten-arc process, using five commercial filler wires. Weld specimens were then subjected to tensile and hardness tests and to metallographic examination, with a view to determining the welding parameters and procedures necessary to achieve the aim of the investigation.

No difficulty was encountered in welding any of the steels with any particular filler wire. More than 90 per cent. of the weld specimens met the minimum yield-strength requirement, though ductility was lower than 5 per cent. in each case. Results obtained on butt joints were more consistent than those obtained with vee-joint specimens. Use of low-alloy-steel filler wires offered no particular advantage, and low-carbon-steel filler metal yielded equivalent results in the thickness range 0·072-0·109 in. (1·8-2·72 mm.).

HEAT- AND CORROSION-RESISTING MATERIALS

Determination of Chromium in Nickel-containing Steels

W. D. NORDLING: 'Photometric Determination of Chromium in Steels and Aluminium Alloys.'
Chemist-Analyst, 1960, vol. 49, Sept., pp. 78-9, 88.

A photometric technique, suitable for determination of chromium in steels and aluminium alloys, and which does not entail the element's prior separation, offers advantages in rapid routine analysis. In the work reported, it was found that chromium can, after solution of the steel or alloy, be determined photometrically by formation of the highly coloured chromium-(III)-ethylenediaminetetraacetate (EDTA) complex. Iron (III), which interferes by forming a coloured complex with EDTA, is first reduced with ascorbic acid to iron (II), which forms a colourless EDTA complex and hence does not interfere.

The data obtained in the determination of chromium in standard steel specimens show that satisfactory results are attainable in those containing up to 14 per cent. nickel and up to 2·9 per cent. cobalt. Other results indicate that cobalt does not interfere at contents less than about 20 per cent. Tungsten (which is removed in the preparation of the sample solution) and molybdenum do not interfere.

Estimation of Ferrite in Chromium-Nickel Stainless Steels

L. PRYCE and K. W. ANDREWS: 'Practical Estimation of Composition Balance and Ferrite Content in Stainless Steels.'

Jnl. Iron and Steel Inst., 1960, vol. 195, Aug., pp. 415–7.

Some grades of austenitic stainless or heat-resisting steel may, at the temperature usually employed for rolling, contain small amounts of ferrite which give rise to difficulties during rolling, and an accurate means of estimating, as a first step to controlling, the amount of ferrite present is therefore desirable. The authors and their co-workers have previously suggested the use, in this connexion, of formulae based on a phase diagram for the three major components (iron, chromium and nickel) and factors for other elements (*ibid.*, 1952, vol. 171, pp. 49–58; 1956, vol. 184, pp. 289–301: see relevant abstracts in volumes 25 and 30 of *The Nickel Bulletin*). In view of the interest aroused by their suggestion, the authors now draw attention to improvements made in the original formulae (especially in relation to the factors for manganese and molybdenum), and refer to developments in the application of the formulae to ferrite control.

The formulae presented for equivalent nickel and chromium contents are to be used with a modified Schaeffler-type diagram (included in the paper) which is based on measurements of ferrite content in commercial heats of steel. Chromium and nickel equivalents have been calculated for 18–8, 18–8–Nb, 18–8–Ti and 18–8–Mo–Ti steels.

The paper also includes formulae representing the conditions under which sigma occurs in steels containing 20–25 per cent. chromium and 15 per cent. nickel. Sigma forms much more rapidly from ferrite than from austenite, and some advantage is obtained by ensuring that the steel is fully austenitic at high temperatures. Complete avoidance imposes further restrictions which are indicated.

Heat- and Corrosion-Resisting Nickel-base Alloys: Aeronautical Material Specifications Covering Sheet, Strip, Bar, Forgings, Flash-Welded Rings and Castings

The *Aeronautical Material Specifications* referred to below were recently issued by the SOCIETY OF AUTOMOTIVE ENGINEERS. The specifications differ little in format and the requirements are (unless otherwise stated in the following abstracts) stipulated in sections covering: Acknowledgement; Form; Application; Composition; Condition; Technical Requirements (heat-treatment; grain-size, hardness and tensile and stress-rupture properties after precipitation-treatment); Quality; Tolerances; Reports of Tests; Identification; Rejections.

To facilitate reference, the limits of composition laid down in the various specifications have been assembled in the table on p. 281.

'Alloy Castings, Investment, Corrosion- and Heat-Resistant, Nickel-base-18Cr-18Co-3Ti-3Al-4Mo-2Fe, Vacuum-Melted and -Cast, Solution- and Precipitation-Treated.'

Aeronautical Material Specification 5384, issued June 30, 1960; 3 pp.

The castings covered are primarily for use in applications (e.g., turbine blades) requiring high-strength at temperature up to 1700°F. (925°C.) and oxidation-resistance at temperatures up to 1800°F. (980°C.).

The technical requirements relate to: production of castings; test specimens; heat-treatment; hardness and tensile and stress-rupture properties.

'Alloy Castings, Investment, Corrosion- and Heat-Resistant, Nickel-base-28Mo-5Fe-0·4V.'

Aeronautical Material Specification 5396, issued June 30, 1960; 3 pp.

The castings (mainly small parts, e.g., exducers and fans, requiring good corrosion-resistance and strength at temperatures up to 1400°F. (760°C.)) are, unless otherwise specified, supplied in the as-cast condition. The technical requirements laid down relate to casting, test specimens, tensile and bend properties, and hardness.

'Alloy Sheet and Strip, Corrosion- and Heat-Resistant, Nickel-base-15·5Cr-3·25Al-0·75Ti.'

Aeronautical Material Specification 5550, issued June 30, 1960; 3 pp.

The specification is relevant to sheet and strip, 'primarily for parts and assemblies requiring oxidation-resistance up to approximately 2000°F. (1095°C.), and where parts require welding during fabrication'. Details are given of the bend test to which sheet is to be subjected and the property requirements which the material (in either form) should satisfy after precipitation-treatment.

'Alloy Sheet and Strip, Corrosion- and Heat-Resistant, Nickel-base-19Cr-10Co-10Mo-1Al-2·5Ti, Vacuum-Melted, Solution-Heat-Treated.'

Aeronautical Material Specification 5551, issued June 30, 1960; 3 pp.

The principal application of the sheet and strip covered is to parts which may be welded during fabrication and which require high strength up to 1500°F. (815°C.) and oxidation-resistance up to 1800°F. (980°C.). Technical requirements relate to solution-treatment, tensile and bend properties in the solution-treated condition, and tensile properties and grain-size after precipitation-treatment.

'Alloy, Corrosion- and Heat-Resistant, Nickel-base-19Cr – 11Co – 10Mo – 3Ti – 1·5Al, Vacuum – Melted, Solution-Treated.'

Aeronautical Material Specification 5712, issued June 30, 1960; 5 pp.

The specification is concerned with bars, forgings, flash-welded rings (and stock for forgings, flash-welded rings or heading) for use principally in

applications (e.g., turbine rotors, shafts, bolts, dowels and fittings) necessitating high strength up to 1600°F. (870°C.) and oxidation-resistance up to 1800°F. (980°C.).

'Alloy, Corrosion- and Heat-Resistant, Nickel-base-19Cr-11Co-10Mo-3Ti-1·5Al, Vacuum-Melted, Solution- and Precipitation-Treated.'

Aeronautical Material Specification 5713, issued June 30, 1960; 4 pp.

The specification relates to material of the same composition, available (excluding stock for heading) in the same forms, and intended for the same applications, as that covered by *A.M.S.* 5712 (*vide supra*).

'Alloy, Corrosion- and Heat-Resistant, 15Cr-45Ni-4W-4Mo-3Ti-1Al, Consumable-Electrode Vacuum-Melted.'

Aeronautical Material Specification 5746, issued June 30, 1960; 4 pp.

The alloy, which is to be supplied in the form of bars, forging stock and heading stock, and, unless otherwise specified, in the solution- and precipitation-treated condition, is intended primarily as a material of construction for parts (such as turbine rotors, shafts, buckets or blades, dowels and fittings) requiring high strength up to 1600°F. (870°C.) and oxidation-resistance up to 1800°F. (980°C.).

'Alloy, Corrosion- and Heat-Resistant, Nickel-base-19Cr-10Co-10Mo-1Al-2·5Ti, Vacuum-Melted, Solution-Treated.'

Aeronautical Material Specification 5756, issued June 30, 1960; 4 pp.

The solution-treated-and-descaled bars, forgings and flash-welded rings (and stock for forging, flash-welded rings or heading) in the alloy covered are for use in components (e.g., turbine shafts, buckets, bolts, dowels and fittings) intended for service in applications demanding oxidation-resistance at temperatures up to 1800°F. (980°C.) and high strength up to 1500°F. (815°C.).

'Alloy, Corrosion- and Heat-Resistant, Nickel-base-19Cr-10Co-10Mo-1Al-2·5Ti, Vacuum-Melted, Solution- and Precipitation-Treated.'

Aeronautical Material Specification 5757, issued June 30, 1960; 4 pp.

The alloy to which the specification relates is intended for the same applications, and is supplied in the same forms, as that covered by *A.M.S.* 5756. In the present specification, however, the bars, forgings, etc., are required, unless otherwise specified, to be solution- and precipitation-treated and descaled.

'Alloy, Corrosion- and Heat-Resistant, Nickel-base, 18Cr-17Co-3Ti-3Al-4Mo-4Fe, Vacuum-Melted, Solution-, Stabilization- and Precipitation-Treated.'

Aeronautical Material Specification 5751, issued June 30, 1960; 3 pp.

The bars, forgings and forging stock conforming to the requirements of the specification are intended for parts, such as turbine blades, bolts and fittings, which must exhibit high strength at temperatures up to 1600°F. (870°C.) and oxidation-resistance up to 1800°F. (980°C.).

Iron-Chromium-Nickel-Cobalt-base Corrosion- and Heat-Resistant Alloy: Specification

SOC. AUTOMOTIVE ENGINEERS: 'Alloy, Corrosion- and Heat-Resistant, Iron-base-20Cr-20Ni-20Co-3Mo-2W-1 (Nb+Ta), Solution-Treated.'

Aeronautical Material Specification 5769, issued June 30, 1960; 3 pp.

The specification relates to an alloy (supplied in the form of bars, forgings and flash-welded rings, and stock for forgings or flash-welded rings) intended for use in components (e.g., turbine rotors, shafts, buckets and bolts) required to exhibit high strength properties at temperatures up to 1350°F. (735°C.) and adequate oxidation-resistance up to 1800°F. (980°C.).

Requirements are stipulated with respect to: condition; technical factors (solution-treatment, hardness, stress-rupture properties); quality; tolerances; reports of tests; identification; rejection.

The composition range laid down is noted in the table on p. 281.

Precipitation-Hardening Stainless Steels: Specifications

SOC. AUTOMOTIVE ENGINEERS: 'Steel Sheet and Strip, Corrosion- and Heat-Resistant, 13·5Cr-26Ni-1·75Mo-3Ti, Vacuum-Melted, Solution-Treated.'

Aeronautical Material Specification 5543, issued June 30, 1960; 3 pp.

Steel sheet, strip and plate conforming to the requirements of this specification are intended mainly for parts exhibiting high strength up to 1350°F. (735°C.) and adequate oxidation-resistance up to 1500°F. (815°C.). The steel may be welded during fabrication and subsequently precipitation-treated (properties after precipitation-treatment are stipulated in the section dealing with technical requirements).

For the composition range covered by the specification, see table on p. 281.

SOC. AUTOMOTIVE ENGINEERS: 'Steel, Corrosion- and Moderate-Heat-Resistant, 15Cr-7·1Ni-2·5Mo-1·1Al.'

Aeronautical Material Specification 5657, issued June 30, 1960; 3 pp.

The steel covered by the specification (for compositional limits see table, p. 281) is supplied, in the form of bars, forgings and forging stock, primarily for components which may require welding during fabrication and which, during service, must exhibit high strength and oxidation-resistance at temperatures up to 700°F. (370°C.). The property requirements which the steel must satisfy after transformation and precipitation-hardening treatments are stipulated.

Aeronautical Materials Specifications: Limits of Composition

(*See abstract on p. 275*)

Specification	C %	Mn %	Si %	P %	S %	Cr %	Ni %	Ni+Co %	Co %	Mo %	W %	Al %	Ti %	Fe %	B %	Other Elements %
A.M.S. 4778A	0·06 max.	—	4·0-5·0	—	—	—	—	90·0-92·0	1·0 max (if determined)	—	—	—	—	1·5 max.	2·2-3·5	—
A.M.S. 4779	0·06 max.	—	3·0-4·0	—	—	—	—	92·0-94·0	1·0 max (if determined)	—	—	—	—	1·5 max.	1·0-2·2	—
A.M.S. 5384	0·10 max.	0·20 max.	0·30 max.	—	0·015 max.	16·0-20·0	remainder	—	16·0-20·0	3·0-5·0	—	2·5-3·25	2·5–3·25	2·0 max.	0·003-0·01	Cu 0·1 max.
A.M.S. 5396	0·12 max.	1·0 max.	1·0 max.	—	0·03 max.	1·0 max.	remainder	—	2·5 max	26·0-30·0	—	—	—	4·0-7·0	—	V 0·2-0·6
A.M.S. 5543	0·08 max.	1·25-2·0	0·10-0·80	0·040 max.	0·03 max.	12·0-15·0	24·0-28·0	—	—	1·25-2·25	—	0·25 max.	2·7-3·3	—	0·025-0·12	Cu 0·25 max.
A.M.S. 5550	0·10 max.	1·00 max.	0·70 max.	—	0·01 max.	14·0-17·0	—	re-mainder	1·0 max (if determined)	—	—	2·75-3·75	0·25-1·0	2·0 max.	—	Cu 0·5 max.
A.M.S. 5551	0·10 max.	0·75 max.	0·75 max.	0·015 max.	0·015 max.	18·0-20·0	remainder	—	9·0-11·0	9·0-11·0	—	0·75-1·3	2·25-3·0	5·0 max.	0·003-0·01	—
A.M.S. 5657	0·09 max.	1·00 max.	1·00 max.	0·040 max.	0·030 max.	14·0-16·0	6·50-7·75	—	—	2·0-3·0	—	0·75-1·5	—	—	—	—
A.M.S. 5712 / A.M.S. 5713	0·12 max.	0·10 max.	0·50 max.	—	0·015 max.	18·0-20·0	remainder	—	10·0-12·0	9·0-10·5	—	1·4-1·8	3·0-3·3	5·0 max.	0·003-0·01	—
A.M.S. 5746	0·08 max.	0·75 max.	0·75 max.	0·040 max.	0·040 max.	14·0-16·0	42·0-48·0	—	—	3·0-4·5	3·0-4·5	0·75-1·3	2·7-3·3	re-mainder	0·008-0·016	—
A.M.S. 5751	0·15 max.	0·75 max.	0·75 max.	—	0·015 max.	15·0-20·0	remainder	—	13·0-20·0	3·0-5·0	—	2·5-3·25	2·5-3·25	4·0 max.	0·003 max.	Cu 0·15 max.
A.M.S. 5756	0·10-0·20	0·75 max.	0·75 max.	0·015 max.	0·015 max.	18·0-20·0	remainder	—	9·0-11·0	9·0-11·0	—	0·75-1·3	2·25-3·0	5·0 max.	0·003-0·01	—
A.M.S. 5757	0·10-0·20	0·75 max.	0·75 max.	—	0·015 max.	18·0-20·0	remainder	—	9·0-11·0	9·0-11·0	—	0·75-1·3	2·25-3·0	5·0 max.	0·003-0·01	—
A.M.S. 5769	0·08-0·16	1·00-2·0	1·00 max.	0·040 max.	0·030 max.	20·0-22·5	19·0-21·0	—	18·5-21·0	2·5-3·5	2·0-3·0	—	—	re-mainder	—	N 0·1-0·2 Nb+Ta 0·75-1·25
A.M.S. 6265	0·07-0·13	0·40-0·7	0·20-0·35	0·025 max.	0·025 max.	1·00-1·4	3·0-3·50	—	—	0·08-0·15	—	—	—	—	—	—
A.M.S. 6276	0·18-0·23	0·75-1·0	0·20-0·35	0·025 max.	0·025 max.	0·40-0·60	0·40-0·70	—	—	0·15-0·25	—	—	—	—	—	—
A.M.S. 6429 / A.M.S. 6435	0·33-0·38	0·60-0·9	0·40-0·60	0·010 max.	0·010 max.	0·65-0·9	1·65-2·0	—	—	0·3-0·4	—	—	—	—	—	V 0·17-0·23

Nickel-base High-Temperature Brazing Alloys: Specifications

The brazing alloys covered by the two *Aeronautical Material Specifications* referred to in the abstracts below are supplied in the form of powder, rod, wire or strip (or as ordered). They are primarily for use in brazing corrosion- and heat-resisting alloys intended for applications where the brazed joint must exhibit high strength and adequate corrosion- and oxidation-resistance at high temperatures. The alloys may also be used, in hard-facing applications, to produce a corrosion- and oxidation-resistant coating. Both alloys flow well in most reducing and neutral atmospheres. The requirements laid down in the two specifications differ only with respect to the compositions of the alloys covered. Stipulations as to the technical factors, dimensions, etc., are the same.

SOC. AUTOMOTIVE ENGINEERS: 'Brazing Alloy, Nickel-base-4·5Si-2·9B.'

Aeronautical Material Specification 4778A, revised June 30, 1960; 3 pp.

Compositional limits are listed in the table on p. 281. The solidus and liquidus temperatures corresponding to this composition range are, respectively, approximately 1770°F. and 1875°F. (965°C. and 1020°C.).

SOC. AUTOMOTIVE ENGINEERS: 'Brazing Alloy, Nickel-base-3·5Si-1·8B.'

Aeronautical Material Specification 4779, issued June 30, 1960; 3 pp.

For the composition range of alloys covered, see table on p. 281. The solidus and liquidus temperatures corresponding to this range are, respectively, approximately 1800°F. and 1950°F. (980°C. and 1065°C.).

Manganese-Nickel-Cobalt-Boron High-Temperature Brazing Alloy

R. C. KOPITUK: 'A New High-Temperature Manganese-base Brazing Alloy.'

Welding Jnl., 1960, vol. 39, Sept., pp. 401s-5s.

The investigation described was initiated to assess the suitability, for rocket-engine applications, of a new high-temperature brazing alloy claimed to combine many of the advantages of silver- and nickel-base alloys. The alloy, containing nickel 16, cobalt 16, boron <1, per cent., remainder manganese, was developed to provide an inherently ductile material exhibiting less alloying effect than the nickel-base brazing alloys.

Since the author's immediate interest lay in the application of the alloy to the brazing of Type 347 18-8-Nb stainless-steel thin-walled tubing, much of the information given centres around this application. The first requirement was to determine optimum flow temperatures. Tests in this connexion indicated that, depending upon the application, good flow characteristics were obtained at temperatures in the range 1850°-1950°F. (1010°-1065°C.). (It is noted that all work, except that involving welding, was conducted in a dry hydrogen atmosphere with a dewpoint of −60°F. (−51°C.). The time at brazing temperature ranged from 15 to 30 minutes.)

The tests reported in the paper were designed to determine: (1) the effects of large brazed fillets on grain growth, undercutting and alloying; (2) the ductility and strength of joints brazed with the alloy; (3) the influence of various heat-treatments on the tensile properties, microhardness and microstructure of brazed joints and of joints fusion welded using the alloy as a filler material.

The data presented are regarded as demonstrating the alloy's suitability for use in brazing and/or welding components intended for high-temperature service. In strength and ductility it surpasses many of the high-temperature brazing alloys currently available.

The various ageing treatments studied had no significant effect on the tensile strength of the brazed joints, and, within the limits of the test conditions, it is concluded that the alloy does not age harden. No microstructural change was observed in specimens subjected for 1 hour to temperatures of 300°, 400°, 600° or 800°F. (150°, 205°, 315° or 425°C.), and, although the dendritic structure of a welded specimen changed markedly when subjected to a heat-treatment identical to that applied to an 'Inconel X' component, the change had no effect on the short-time physical properties of the joint.

Electrodeposition of Nickel-Zinc-Alloy Corrosion-Resistant Coatings: Specification

See abstract on p. 272.

Adherence of Oxide Films on Metals

R. F. TYLECOTE: 'The Adherence of Oxide Films on Metals: A Review of Information.'

Jnl. Iron and Steel Inst., 1960, vol. 195, Aug., pp. 380-5.

The adherence of oxide films on metals, steels and alloys is a factor of great importance in the field of high-temperature materials: the protection conferred by an oxide film under laboratory conditions is of little practical value if the film is not adherent over long periods during actual service. In this paper (in which reference is made to a *bibliography* of 45 items) the author discusses the relationships thought likely to be relevant to adherence, and directs attention to those aspects of the subject that seem important and worthy of further investigation. He restricts his discussion to data available on pure metals (e.g., nickel) and the simpler atmospheres and alloys (including nickel-chromium alloys), since it was felt that knowledge of the adherence of superficial films present on complex alloys in industrial atmospheres was as yet insufficient for any useful assessment of the factors involved.

Volume ratio, surface configuration, film plasticity, the diffusion mechanism, and the relevant expansion coefficients of metal and oxide are among the factors

whose influence is taken into account. The effect of the last two variables is deemed important. In the absence of plasticity, it is felt that adherence at high temperatures is determined primarily by the attainment of a balance between inward and outward diffusion of metal and oxygen ions. In non-plastic films, differential contraction on cooling can result in the spalling of otherwise adherent films. With regard to pure metals, minor impurities and the oxidizing atmosphere are very influential.

Influence of Heat-Treatment on the Creep-Rupture Properties of Chromium-Nickel-Titanium Stainless Steel

M. NISHIHARA, H. HIRANO, S. YAMAMOTO and K. YOSHIDA: 'Study on Type 321 Stainless Steel Intended for High-Temperature Service.'

Proc. 3rd Japan Congress on Testing Materials, 1960, pp. 72–6.

Published by *Japan Soc. Testing Materials.*

A.I.S.I. Type 321 titanium-stabilized chromium-nickel stainless steel exhibits a creep-rupture strength superior to that of an 18–8 titanium-free grade and is widely used as a material of construction for superheater and reheater tubing. Titanium, a strong carbide-forming element, is present either in solution in the austenite or in the form of a carbide or other type of precipitate. In the work reported, the authors have studied the influence of heat-treatment (in particular, those designed to induce precipitation of titanium carbide) on the creep-rupture properties of Type 321 steel.

Two heats of steel, one melted *in vacuo*, the other in air, were selected for investigation (see composition below).

C %	Si %	Mn %	P %	S %	Ni %	Cr %	Ti %	Melting Method
0·069	0·65	1·98	0·009	0·02	12·73	16·72	0·58	Vacuum-Melted
0·10	1·00	1·75	0·009	0·03	12·89	17·61	0·32	Air-Melted

Specimens were subjected to one of the following five heat-treatments prior to creep testing at 650°C.:

(1) 1300°C. for 2 hr.; water quench: designed to dissolve any titanium carbide present and to coarsen the grain-size.

(2) 1300°C. for 2 hr.; W.Q.; 1000°C. for 2 hr.; W.Q.: intended to precipitate titanium carbide up to equilibrium value at 1000°C. after a grain-coarsening treatment.

(3) 1000°C. for 2 hr.; W.Q.: designed to cause precipitation similar to (2) without grain coarsening.

(4) 1050°C. for 2 hr.; W.Q.: designed to induce precipitation of titanium carbide up to equilibrium value at 1050°C.

(5) 1300°C. for 2 hr.; W.Q.; 800°C. for 8 hr.; W.Q.: designed to induce precipitation of titanium carbide up to equilibrium value at 800°C. after grain-coarsening treatment.

Specimens were examined, by electron microscopy and X-ray diffraction, to determine the effects of creep on the precipitates present.

The data presented in the paper reveal that the creep-rupture strength of Type 321 steel is considerably influenced by heat-treatment and by precipitation of titanium carbide (see table on p. 284).

The highest creep-rupture strength was exhibited by specimens heat-treated in accordance with procedure (1), but the grain coarsening involved in exposure to such a high temperature was such as to reduce ductility. The shortest rupture life was shown by specimens submitted to heat-treatments (2) or (3) (indicating the significant effects of the titanium carbide precipitated at 1000°C.), but, even after these heat-treatments, the creep-rupture strength of the steel was superior to that of an 18–8 titanium-free grade. Grain-size influenced ductility, but not creep-rupture strength. On the basis of these findings, the authors recommend that quenching temperatures should be higher than 1100°C.

The data obtained also demonstrate that, irrespective of the carbon/titanium ratio (1/3 and 1/8), the steels do not differ significantly in creep-rupture behaviour. Specimens of the air-melted grade (carbon/titanium ratio = 1/3), when subjected to creep-rupture tests at various temperatures in the range 550°–650°C., exhibited higher strengths than those reported for Type 321 steels in *A.S.T.M. Special Technical Publication* 124.

Stress-Rupture Properties of an Aluminium-Nickel-Iron Alloy

V. DE L. DAVIES: 'Stress-Rupture Testing of Aluminium-1% Nickel-0·5% Iron Alloy.'

Jnl. Inst. Metals, 1960, vol. 89, Sept., pp. 22–3.

Due to its corrosion-resistance in high-temperature water, an aluminium alloy containing 1 per cent. nickel and 0·5 per cent. iron has attained some interest as a potential canning material for fuel elements in nuclear reactors (see, for example, papers referred to in *Nickel Bulletin*, 1960, vol. 33, No. 3, pp. 58–60). Information concerning the mechanical properties of this alloy is, however, very scarce, and, in particular, little or nothing is known about its strength at elevated temperatures. The study reported, conducted within the framework of a programme directed towards developing aluminium alloys for use as canning materials in water-cooled power reactors, was initiated, by the Norwegian Institute for Atomic Energy, to provide data on the mechanical properties of such alloys at elevated temperatures.

The alloy tested contained approximately 1 per cent. nickel and 0·55 per cent. iron. The work described was exploratory, and the test conditions were selected to produce rupture after 1, 10, 100 and 500

Creep-Rupture Strength of 17-13-Ti Steels

(*See abstract on p. 283*)

Test Specimen	Heat-Treatment	Rupture Time (hour)	Maximum Creep Rate (%/hour)	Elongation at Rupture %	Reduction-in-area %
Air-Melted	(1)	743·8	0·00088	3·3	8·6
	(2)	93·1	0·0206	14·0	30·5
	(3)	104·5	0·055	44·0	64·0
	(4)	377·3	0·0081	23·3	33
	(5)	363	0·0070	20·0	36·0
Vacuum-Melted	(1)	714	0·00086	12·3	17·5
	(2)	41·2	0·048	15·0	36·4
	(4)	259	0·0125	43·3	72·0
	(5)	177	0·0375	21·7	48·6

hours at nominal testing temperatures of 150°, 200°, 250°, 300° and 350°C.

Strength properties were found to be rather poor, and the alloy is not regarded as a satisfactory material of construction for elevated-temperature applications: the stresses for a 1000-hour rupture life were approximately 0·75 kg./mm.^{2} at 350°C., 1·8 kg./mm.^{2} at 250°C., and 4·2 kg./mm.^{2} at 150°C. These combinations of stress and temperature gave a minimum creep rate of approximately 0·01 per cent./hour.

For test temperatures both below and above the recrystallization range, the results are represented by straight lines with no appreciable deviations. At 250°C. (i.e., at the lower limit of the recrystallization range) the results exhibited some scatter. A metallographic study, which was carried out in an effort to establish the reason for this scatter, indicated that in this range the stress-rupture results are somewhat sensitive to the particle size and distribution of the intermetallic phase: a continuous and finely dispersed *T* phase around the α grains is deemed likely to give better and more consistent results than those associated with a discontinuous and coarse distribution of the phase.

Corrosion Behaviour of Architectural Steels and Alloys in Canadian Atmospheres

NAT. RESEARCH COUNCIL OF CANADA, ASSOCIATE COMMITTEE ON CORROSION RESEARCH AND PREVENTION: 'The Corrosion Behaviour of the Major Architectural and Structural Metals in Canadian Atmospheres: Summary of Two-Year Results.'

Report by Sub-Committee C, Atmospheric-Corrosion Testing, Ottawa, Feb. 24, 1959; 23 pp.+figures and tables.

The work reported was initiated, in the light of the increasing industrialization of Canada, to supplement the relatively few data available on the behaviour of the principal architectural and structural metals in Canadian atmospheres.

The following materials were selected for evaluation:

(1) Aluminium Alloys: (*a*) 'Alcan 3S-H14';
(*b*) 'Alcan 57S-H34';
(*c*) 'Alcan 65S-T6';
(*d*) 'Alcan 3S-H14' riveted to cobalt, zirconium or mild steel.

(2) A.S.T.M. Standard Steel

(3) A.S.T.M. Standard Zinc

(4) Low-Alloy Steels: (*a*) Low-alloy residual;
(*b*) Copper-bearing (0·205 per cent.);
(*c*) Copper-nickel (Cu 0·738, Ni 0·68 per cent.).

(5) Chromium-Nickel Stainless Steels:
(*a*) A.I.S.I. Type 302 (18-8);
(*b*) A.I.S.I. Type 316 (17-13-Mo);
(*c*) A.I.S.I. Type 430 (17 per cent. Cr).

(6) Magnesium Alloys: (*a*) 'AZ80X';
(*b*) 'ZK61X'.

(7) Rolled zinc.

Sheet-panel specimens of each of these materials were exposed for various periods at the following eight sites (the type of atmosphere associated with each site is noted in parentheses): (1) Ottawa (semi-rural), (2) Saskatoon (rural), (3) Montreal (industrial), (4) Halifax (marine-industrial), (5) Halifax (rural-marine), (6) Norman Wells (90 miles south of the Arctic Circle), (7) Esquimault (rural-marine), (8) Trail (semi-rural). One lot of panels was removed for inspection after exposure for one year, and a second lot was removed after two years. The data summarized in the present report relate to these panels: two lots of panels remain exposed and will be evaluated at later dates.

The degree to which the specimens were corroded was assessed on the basis of appearance, weight-loss and depth of pitting. The sulphur-dioxide content of the air was determined monthly at each site. In the report full details are given of the experimental

Corrosion Rates of Materials Exposed for Two Years in Sites in Canada

(*See abstract on p. 284*)

Site Location	Corrosion Rate in mils/year (based on loss-in-weight)												
	Aluminium			A.S.T.M.		Alloy Steels			Stainless Steel (A.I.S.I. Type)			Magnesium		Rolled Zinc
	3S	57S	65S	Zinc	Steel	Residual	Cu	Cu-Ni	302	316	430	AZ80	ZK61	
Ottawa ..	0·010	0·014	0·010	0·060	0·9	0·9	0·8	0·6	*	—	—	0·284	1·04	0·047
Saskatoon ..	0·004	0·008	0·005	0·030	0·60	0·55	0·52	0·42	—	—	—	0·157	0·68	0·017
Montreal ..	0·036	0·029	0·039	0·138	1·3	1·3	1·2	0·82	—	—	—	0·75	1·72	0·114
Halifax (industrial) ..	0·63	0·43	0·43	1·03	3·5	2·9	3·0	2·0	0·019	0·013	0·049	3·64	4·44	0·851
Halifax (rural) ..	0·014	0·015	0·016	0·097	1·4	1·2	1·1	0·9	—	—	—	0·432	1·69	0·067
Norman Wells	0·002	0·005	0·004	0·014	0·020	0·025	0·0	0·025	—	—	—	0·049	0·44	0·009
Esquimault ..	0·003	0·008	0·005	0·018	0·47	0·41	0·38	0·34	—	—	—	0·142	0·702	0·020
Trail	0·016	0·016	0·014	—	—	1·3	1·3	0·88	—	—	—	1·84	1·69	0·078

*Except for the Halifax (industrial) site, corrosion rates for the stainless steels were very low.

procedures employed, the specimens used and the data obtained. The corrosion behaviour of each of the materials is discussed in relation to the exposure site, and the data tabulated are supplemented by diagrams correlating the corrosion rates exhibited by a specific material at different sites, or those exhibited by the different materials at a specific site. The corrosion data relative to the two-year exposure period are reproduced in the table above.

The rate of atmospheric corrosion was markedly influenced by the sulphur-dioxide content of the atmosphere. It would, it is considered, be premature to draw definite conclusions from data available only for two relatively early points on the corrosion/time curve, but it is, nevertheless, tentatively concluded that, of the materials tested, the stainless steels exhibited the most satisfactory atmospheric corrosion-resistance (corrosion being negligible at all sites except Halifax). The performance of the three aluminium alloys, which were the next best in order of corrosion-resistance, did not vary greatly.

With the exception of the low-alloy steels, no decrease was observed in the corrosion rates exhibited by the materials tested during the one- and two-year periods.

Corrosion Problems in a Refinery Diethanolamine System

K. L. MOORE: 'Corrosion Problems in a Refinery Diethanolamine System.'

Corrosion, 1960, vol. 16, Oct., pp. 503t–6t.

The aim of the present paper is to outline the corrosion problems encountered in the single diethanolamine (D.E.A.) system employed by the Tidewater Oil Company, at its Delaware Refinery, to remove hydrogen sulphide from refinery gas streams and a liquid propane-butane stream.

Problems discussed include cases of (1) reboiler corrosion, (2) corrosion in rich D.E.A., and (3) stress-corrosion cracking and corrosion-erosion. The effects of these problems on system operation is considered, and attention is directed to the methods by which corrosion has been minimized. Use of Type 304 stainless steel for the yokes retaining the bubble caps in the regenerator has, for example, solved the problem of stress corrosion, and substitution of the same steel for the cast iron originally used in the impellers of the main lean-D.E.A. circulation pumps has greatly extended service life; in other cases modification of the operating conditions has effectively eliminated corrosion problems.

Compatibility of Materials with Unsymmetrical Dimethylhydrazine Rocket Fuel

C. W. RALEIGH and P. F. DERR: 'Compatibility of Materials with Unsymmetrical Dimethylhydrazine Rocket Fuel.'

Corrosion, 1960, vol. 16, Oct., pp. 507t–11t; disc., p. 511t.

The transition of unsymmetrical dimethylhydrazine (U.D.M.H.), one of the newer liquid rocket fuels currently in operational use in the United States, from the laboratory stage to commercial production took less than three years. A programme to determine the compatibility of various materials with U.D.M.H. has, however, been in progress for some time, and, in this paper, the authors present relevant corrosion

data collected over the past six years on various metallic materials, elastomers and plastics.

The data, derived from coupon tests and experience in storing, shipping and handling the fuel, indicate that aluminium and its alloys, the A.I.S.I. 300 series of chromium-nickel stainless steels, Type 416 chromium stainless steel, the precipitation-hardenable steels 'A-286', 'P.H. 15-7 Mo' and '17-7 P.H.', 'Hastelloy B', 'Hastelloy C', 'Hastelloy F' and 'Hastelloy X', and titanium and its alloys exhibit satisfactory compatibility. Elastomers and plastics found compatible with U.D.M.H. include butyl rubbers, 'Hydropol-T', 'Teflon', unplasticized 'Kel-F' and polyethylene.

Mechanism of Stress-Corrosion Cracking of Austenitic Stainless Steels.

D. VAN ROOYEN: 'Qualitative Mechanism of Stress-Corrosion Cracking of Austenitic Steels.'

Corrosion, 1960, vol. 16, Sept., pp. 421t-9t.

In the introductory section of the paper the author reviews the literature concerned with the mechanism of stress-corrosion cracking of austenitic stainless steels and draws the conclusion that considerable disagreement and uncertainty exists with respect to the exact way in which cracks penetrate the steels. The experiments described were conducted on the assumption that a clear understanding of qualitative crack growth is a prerequisite to further quantitive studies.

Five materials were selected for study: U-bend and wire specimens in a commercial stainless steel (composition: carbon 0·057, silicon 0·55, manganese 0·71, phosphorus 0·035, sulphur 0·03, nitrogen 0·068, aluminium 0·058, chromium 18·6, nickel 9·45, per cent.); mild-steel strip; magnesium-alloy strip; aluminium-copper-alloy strip; and aluminium-magnesium-alloy strip. Cracking was studied as a function of changes in electrochemical potential, the extension of specimens during cracking, and the sound generated in the course of failure. The observations were made in sufficient detail to indicate any sudden steps in the process.

From the data obtained it is concluded that cracking of the austenitic stainless steel and the magnesium-base alloy in chloride solutions was a gradual process involving no sign of steps of sudden fracture. Mild steel in nitrate solutions was found to crack in an uneven way: the tests revealed the occurrence of alternating slow and rapid stages, but the rapid stages did not approach the speed of brittle fracture.

Aluminium-magnesium and aluminium-copper alloys exposed to a mixture of sodium-chloride and sodium-bicarbonate solutions exhibited stress-corrosion-crack propagation in alternating steps of electrochemical corrosion and instantaneous physical fracture.

In reviewing these findings, the author suggests an electrochemical mechanism of crack propagation as a major factor in the gradual stages of cracking of the materials studied. The evidence available is not, however, regarded as excluding the mechanism by which cracks extend under the combined influence of stress and the lowering of surface energy of adsorption on the walls of newly forming cracks.

(See, in connexion with this paper, that by the same author referred to in *Nickel Bulletin*, 1960, vol. 33, No. 10, p. 253.)

Compositional Effects in the Corrosion of 18-8-Nb and 18-8-Mo Austenitic Steels

C. P. DILLON: 'Compositional Effects in the Corrosion of Type 347 and 316 Stainless Steel in Chemical Environments.'

Corrosion, 1960, vol. 16, Sept. pp. 433t-9t; disc., pp. 439t-40t.

This paper was presented at the 16th Annual Conference of the National Association of Corrosion Engineers; see abstract of preprint in *Nickel Bulletin*, 1960, vol. 33, No. 7, p. 178.

Potentiostatic Study of the Susceptibility of Stainless Steels to Intergranular Corrosion

V. CÍHAL and M. PRAZÁK: 'A Contribution to the Explanation of Intergranular Corrosion of Chromium-Nickel Steel.'

Corrosion, 1960, vol. 16, Oct., pp. 530t-2t.

In the introductory section of their paper, the authors discuss the mechanism involved in intergranular corrosion of chromium-nickel stainless steel. In considering the relationship between carbide precipitation at the grain boundaries and a steel's susceptibility to such attack, they apply the findings of electrochemical studies of iron-chromium alloys to the conditions obtaining at the grain boundaries of a sensitized 18-8-type steel. They postulate that because the carbides which are precipitated, $(CrFe)_{23}C_6$, can take as much as 30 at. per cent. of iron into solid solution, not only will the chromium content decrease in the region of the carbide particles, but the nickel content will, at the same time, rise above the original 8-9 per cent. present in the steel. According to the amount of carbide precipitated, the intercrystalline material can be regarded as a nickel alloy with a variable chromium content. With variation in the chromium content adjacent to the grain boundary, the passivation potential should change from that of an 18-8 steel to, in the limiting case, the passivation potential of an iron-nickel alloy. The increase in passivation potential will decrease the passivating tendency of the grain boundaries. Under these conditions, the grain boundaries with a low chromium content could remain in an active state and corrode, while the rest of the austenitic grain remains passive and, therefore, resistant to corrosion. The experiments carried out to verify these assumptions are described in the main part of the paper.

Polarization curves in normal sulphuric acid at 20°C. were obtained (using a potentiostat) for the 65-35 iron-nickel alloy 'Invar', and for annealed and sensitized specimens of a stainless steel of the following composition: carbon 0·05, silicon 0·62, manganese

1·5, chromium 18·48, nickel 9·34, per cent. In the case of the stainless steel, the data from these electrochemical observations were then compared with the results of intergranular-corrosion tests on similarly annealed or sensitized specimens.

On the basis of this comparison, the authors regard the potentiostatic procedures employed in the investigation as a useful means of determining susceptibility to intergranular corrosion, especially in the case of steels which, with low carbon content or containing stabilizing elements, exhibit only a slight tendency to intergranular corrosion, and, hence, are difficult to evaluate by conventional procedures. The degree of susceptibility to intergranular corrosion is considered to depend on the amount of chromium carbide precipitated and on the Redox potential of the solution. Reduction of the chromium content adjacent to the carbide will change the passivation potential of the grain boundary, moving it in the noble direction. The passivation potential of the grain boundary will, in the limiting case, approach the value of the passivation potential of an alloy containing only iron and nickel.

Selective Removal of Chromium from 18-8 Steel Exposed to Fused Salts

C. EDELEANU, J. G. GIBSON and J. E. MEREDITH: 'Effects of Diffusion on Corrosion of Metals by Fused Salts.' *Jnl. Iron and Steel Inst.*, 1960, vol. 196, Sept., pp. 59–61.

Although the factors which influence corrosion in fused salts are basically the same as those associated with corrosion in aqueous electrolytes, the relative importance of these factors can differ greatly between the two types of electrolyte. One such factor is diffusion in the metal: in the case of fused salts, an extreme example is the internal oxidation of alloys. In the present note the authors draw attention to a type of corrosion in which one constituent of an alloy steel was extracted selectively.

The 18–8 chromium-nickel steel was exposed for about 100 hours in a fused 50/50 NaCl/KCl melt at 800°C. in the presence of air. It was found to suffer what at first appeared to be ordinary intergranular corrosion. More detailed examination showed, however, that the attack was not continuous at the boundaries, and that, especially away from the surface, the specimen merely contained voids which did not seem to be in communication with each other or the exterior of the specimen. Examination of specimens lightly etched in 20 per cent. nitric acid (i.e., in a solution which should not attack a steel containing 18 per cent. chromium) revealed a second series of very small voids around the larger voids and just below the outer surface. The material etched by the nitric acid was within the area between the large and the small voids.

As the simplest interpretation of these findings the authors postulate that chromium is selectively removed by the corrosion reaction, and, as it diffuses outwards, the vacancies move inwards and segregate to form visible voids. The diffusion rate at boundaries is likely to be very much faster than in the grains, so that the chromium in, and adjacent to, the grain boundaries would diffuse relatively rapidly. The formation of voids at boundaries would probably assist the process, since, once they are formed, the chromium would diffuse outwards partially by surface diffusion, which is a faster process. As fresh vacancies arrive, the voids would grow, and eventually are likely to join up to give the appearance of intergranular corrosion.

Corrosion of Austenitic Stainless Steels by Air-Contaminated Lithium.

R. E. SEEBOLD, L. S. BIRKS and E. J. BROOKS: 'Selective removal of Chromium from Type 304 Stainless Steel by Air–Contaminated Lithium.'

Corrosion, 1960, vol. 16, Sept., pp. 468t–70t.

In the recent past the use of liquid metals as heat-exchange media has attracted considerable attention. The major problem, particularly in relation to temperatures in the region of 1500°F. (815°C.), has been that of determining a suitable container material (i.e., one which would be inert to the liquid metal). In the experiments now reported, the corrosion behaviour of Type 304 18–8 chromium-nickel stainless steel in high-purity and air-conditioned lithium was studied in a non-isothermal closed system at maximum and minimum temperatures of 1500° and 800°F. (850° and 425°C.).

The apparatus used was so designed that conditions existing at 1500°F. in the lithium/stainless-steel system could be 'frozen' for study by X-ray, chemical and metallographic analysis at room temperature. The Type 304 stainless-steel tube specimens (closed by a heli-arc weldment at the lower end, and by an O-ring seal at the upper end) were charged with high-purity lithium under a helium atmosphere, high-purity lithium under air, or long-time air-contaminated lithium under air, and placed in furnaces which enclosed their lower ends.

In those experiments involving exposure to high-purity lithium under a helium atmosphere, mass-transfer action after 720 hours at 1500°F. was only slight, and spectrochemical analysis indicated that the mass-transfer deposit was composed of all the constituents of the stainless steel. Metallographic examination of the furnace zone of the container revealed only mild intergranular penetration, to a depth of no more than one grain diameter.

In air-contaminated lithium at 1500°F., chromium was selectively removed from the surface of the steel to depths of 10 microns and remained dissolved in the lithium (in which it is soluble to the extent of at least 25 per cent.). The other constituents of the steel were mass-transferred in their original relative proportions and deposited as strongly magnetic dendrites. This preferential leaching of chromium is proposed as the initial stage in the corrosion of stainless steel by air-contaminated lithium.

Serrations in the Stress/Strain Curve of 18-8 Steel at 20°K

J. F. WATSON and J. L. CHRISTIAN: 'Serrations in the Stress/Strain Curve of Cold-Worked 301 Stainless Steel at 20°K.'

Jnl. Iron and Steel Inst., 1960, vol. 195, Aug., p. 439.

Reports of recent studies of flow and fracture in various metals and alloys at 4·3°K. and 20°K. have drawn attention to serrations (i.e., sudden discontinuous drops in load) observed in the stress/strain curve obtained during tensile testing. The cause of these serrations has been variously attributed to: thermal instability (i.e., plastic strain liberating sufficient thermal energy on certain slip planes to cause increases in temperature large enough appreciably to reduce the flow stress); deformation twinning; and burst-type formation of dislocations. Similar serrations and stress/strain curves were determined by the present authors during tensile testing of extra-full-hard Type 301 18-8 chromium-nickel stainless-steel sheet at 20°K. It is suggested that the mechanism of deformation accounting for the observed serration in this particular steel is the discontinuous occurrence of the austenite-to-martensite reaction. It is believed that the drops in load were caused by the sudden shear-type formation of martensite (due to the greater volume of the martensite phase which momentarily released the load on the specimen).

Work at the authors' laboratory has shown also that the occurrence of serrations in austenitic stainless-steel sheet is dependent upon material variables (i.e., chemistry, degree of cold work, thickness) and upon testing conditions (i.e., test temperature, strain rate and the presence of stress concentrations).

Steel for the Containment of Liquefied-Gas Cargoes

See abstract on p. 276.

Stainless Steels for Low-Temperature Service

See abstract on p. 277.

Cracking Tests for Assessing Weldability

See abstract on p. 271.

Welding Metallurgy of the 'Nimonic' Alloys

J. HINDE and D. R. THORNEYCROFT: 'Welding Metallurgy of the Nimonic Alloys.'

Brit. Welding Jnl., 1960, vol. 7, Oct., pp. 605-14.

Most of the nickel-chromium high-temperature alloys of the 'Nimonic' series were developed primarily for gas-turbine blading, and not until their use was extended to other components of the turbine was it necessary to weld them in the form of sheet, bar or castings. As a result of new developments, involving further extension of the range of high-temperature applications to other branches of engineering, the alloys have now to be welded (e.g., in the fabrication of industrial heat-treatment plant or steam plant) in plate, tubing and piping of relatively thick section. The welding response of the members of the 'Nimonic' series (and, in particular, that of 'Nimonic 80A', 'Nimonic 90' and the corresponding casting alloys) has therefore received attention: the main information available in this connexion is reviewed in the present paper.

The welding metallurgy of the following materials is covered: 'Nimonic 75', 'Nimonic 80A', 'Nimonic 90', 'Nimonic 105' (wrought alloys); 'Nimocast 75', 'Nimocast 80', 'Nimocast 90', 'Nimocast 242', 'Nimocast 257', 'Nimocast 258', 'Nimocast 713C' (casting alloys).

The constitution and physical properties of these alloys are discussed in relation to their influence on welding characteristics, and the effects of the solution- and precipitation-hardening heat-treatments employed to develop optimum high-temperature properties are then correlated with the behaviour of the respective materials under the thermal conditions imposed during welding. In subsequent sections of the paper, data on the mechanical properties of the basis metals and welded joints are presented (and discussed with particular reference to the effects of the various temperatures attained by the weld itself and by the adjacent heat-affected zones). Welding procedures are recommended for both wrought and cast alloys, and, in a section on brazing techniques and materials, attention is directed to the feasibility of combining the brazing operation with the thermal-hardening treatment required for certain of the alloys.

Repair Welding of 'René 41' and 'Astroloy'

W. J. LEPKOWSKI, R. E. MONROE and P. J. RIEPPEL: 'Studies on Repair Welding Age-Hardenable Nickel-base Alloys.'

Welding Jnl., 1960, vol. 39, Sept., pp. 392s-400s.

At the temperatures involved in their ageing treatment, some precipitation-hardenable high-temperature alloys exhibit reduced ductility, and, in the case of components welded into highly restrained parts, cracking may occur during ageing. Since repair welding is often, therefore, necessary, the investigation reported was initiated with the main aim of evolving and evaluating welding procedures which, when applied to repair of the nickel-base alloys 'René 41' and 'Astroloy', would produce welds which would not fail during subsequent re-ageing treatment or service. Complementary to this main aim, experiments were conducted (1) to evaluate filler materials and (2) to determine the minimum heating rate which would not entail cracking of weld specimens heated through the ageing range during solution-treatment.

The composition of the basis and filler materials employed in the study are given in the table on p. 289. The basis materials were investigated in the form of 0·03-, 0·045-, 0·06- and 0·075-in. sheet.

Composition of Basis and Filler Materials

(*See abstract on p. 288*)

Material	Mill-annealed hardness	C %	B %	P %	Si %	Mn %	S %	Fe %	Co %	Mo %	Cr %	Ti %	Al %	Ni %	Others
Basis Alloy															
'René 41' ..	Rc30	0·093	0·005	0·004	0·08	0·01	0·01	2·18	11·0	9·55	18·85	3·12	1·59	Bal.	—
'René 41' ..	Rb96	0·11	0·007	—	0·28	0·02	—	1·07	11·17	9·92	18·68	3·08	1·45	Bal.	—
'René 41' ..	Rb99	0·11	0·004	—	0·16	0·02	—	0·78	10·40	9·86	19·62	3·18	1·56	Bal.	—
'René 41' ..	Rb97	0·03	0·011	—	0·16	0·02	—	0·48	11·03	9·62	18·9	3·27	1·51	Bal.	—
'Astroloy' ..	Rc33	0·06	0·03	—	0·1*	0·1*	—	0·2*	15·0	5·0	15·0	3·5	4·5	Bal.	—
Filler metals															
'René 41' ..	—	0·09	—	—	0·1	0·1	—	—	11	10	19	3·1	1·5	Bal.	—
'Hastelloy X'	—	0·15	—	—	—	—	—	24	—	9	22	—	—	45	—
'Hastelloy W'	—	0·12*	—	—	1·0*	1·0*	—	5·5	2·5*	25·0	5	—	—	60	0·6 V*

*Maximum.

The test programme comprised four main phases:

(1) Repair welds were made, using the inert-gas-shielded tungsten-arc technique, on restrained material in the aged condition. The specimens were then subjected to thermal cycles simulating jet-engine operation, and finally examined by radiographic and dye-pentrant techniques.

(2) A study was made of the efficacy of the following procedures (which were designed to overcome the problem of cracking after repair welding):

(*a*) Minimizing the heat input by using as thin a filler wire as possible (30 mils in diameter);

(*b*) Minimizing temperatures in the heat-affected zone by using a water-cooled copper top plate during the welding operation;

(*c*) Pre-heating the specimens at 1000°F. (540°C.) before the solution-treatment which followed the welding operation;

(*d*) Solution-treating the repair weld at 1950°F. (1065°C.) for 5 minutes with a gas torch;

(*e*) Improving the ductility of the basis metal at the ageing temperature by using a double-ageing treatment;

(*f*) Cold working the surface of the repaired specimens by a hammer-peening operation at room temperature;

(*g*) Pre-heating at 1000°F. (540°C.) before repair welding.

(3) The filler materials studied were evaluated as a function of (a) the occurrence of cracks in welded specimens of René 41, and (b) the tensile properties (at room temperature and 1400°F. (760°C.)) of the weld produced. 'Hastelloy X' was used as a filler material in all the welding experiments on 'Astroloy'.

(4) To determine the minimum rate of heating that would not entail cracking in restrained welds, weld specimens were heated, at various rates, through the ageing temperature range.

The results presented are supplemented by photomicrographs illustrating the structures of the welds studied.

Irrespective of the composition and plate thickness of 'René 41', the only techniques found to prevent repair welds from cracking during re-ageing treatment at 1400°F. (760°C.) were a localized solution-treatment at 1950°F. (1065°C.) for 5 minutes, or hammer-peening at room temperature. Evaluation of 'Astroloy' was limited, since the major emphasis in the fusion-welding experiments was on 'René 41'. Specimens of 'Astroloy' usually crack during solution-treatment after welding, mainly in the basis metal and transverse to, or through, the weld metal. A post-weld hammer-peening operation at room temperature was found effectively to prevent such cracking, and the same technique was used successfully prior to ageing treatment and re-ageing treatment after repair welding.

The results of the experiments comprising phase (4) of the investigation demonstrated that, irrespective of the degree of restraint, the rate of heating was not the only major factor in preventing cracking of mill-annealed 'Astroloy'. In the case of 'René 41', it was not found possible to make a specimen involving sufficient restraint to cause failure during heating, even at such a low rate as 10°F. (6°C.) per minute.

In phase (3), tests on 'René 41' specimens revealed that more cracks resulted in weld metal deposited by 'Hastelloy X' filler metal than in that laid down with 'Hastelloy W' or 'René 41' filler metal. The results of the tensile tests carried out within the scope of phase (3) indicated no significant difference in the properties of the specimens welded with the various filler materials. Scatter in the data rendered it difficult to draw any definite conclusions about the relative performance of each filler material.

Distribution of Phosphorus and Sulphur in 25-20 Stainless-Steel Welds

S. M. MAKIN, C. B. ALCOCK, D. R. ARKELL and P. C. L. PFEIL: 'Distribution of Phosphorus and Sulphur in Fully-Austenitic Stainless-Steel Welds.'

Brit. Welding Jnl., 1960, vol. 7, Oct., pp. 595–9.

The cladding of a nuclear-reactor fuel element is fabricated from light-gauge tubing, and welding problems might reasonably be expected to be insignificant. In view of the thermal and stress cycling involved in the service conditions, however, the presence of cavities or fine cracks in the weld metal could limit the life of the fuel element and add to the costs of power production. In a recent review of the literature on the cracking of welds in chromium-nickel austenitic steels BORLAND and YOUNGER indicated, inter alia, that sulphur and phosphorus might play an important rôle in the formation of cracks, though the precise mechanism is not clear (see *Nickel Bulletin*, 1960, vol. 33, No. 3, pp. 63–4). The study reported by the authors was initiated to investigate any change in the distribution of the two elements in welded, *vis-à-vis* fabricated, material.

Since sulphur and phosphorus both have β-emitting radio-isotopes, the radioactive element was incorporated into a steel billet which was then arc-melted and rolled; the resultant sheet was used to make butt welds and weld runs, and a study was made of the distribution of the two radioactive elements (S^{35} and P^{32}) in the welds. The nominal composition of the steel sheet was: carbon 0·08, silicon 1·37, manganese 0·81, chromium 23·7, nickel 21, per cent. The influence of sulphur and phosphorus was studied separately at contents of, respectively, 0·035 and 0·033 per cent.

The concentration of phosphorus in the middle region of the weld zone was found to be measurably greater than in the original sheet, an effect which is attributed to depletion of the first metal to solidify along the sides of the weld. Supplementary experiments on a basically similar steel demonstrated that phosphorus also concentrated in the interdendritic regions of a casting. This element is therefore deemed to be important in the hot-cracking of fully-austenitic stainless-steel welds.

Sulphur, which was not concentrated preferentially in the weld metal, is not, however, considered to play a significant rôle in the formation of cracks observed in these welds.

Welding of Stainless Steel, 'Inconel' and 'Monel' for Use in Plant Handling Radioactive Process Liquors

F. S. DICKINSON and B. WATKINS: 'Use of Welding in Chemical Plants in the U.K.A.E.A.'

Brit. Welding Jnl., 1960, vol. 7, Oct., pp. 643–51.

The standard of weld quality demanded in chemical plants associated with the United Kingdom atomic-energy programme is extremely high, even when the materials handled are not radioactive. The chemical separation plant for the extraction of plutonium from irradiated fuel elements at Windscale has now completed about 10 years' service without leakage, a performance which is particularly noteworthy since 5,000 tons of welded plate, and approximately 50,000 pipe butt welds, were used in its construction. The increasing amount of irradiated fuel to be processed from nuclear reactors operated by the United Kingdom Atomic Energy Authority, and from the gas-cooled reactors now being constructed for the Central Electricity Generating Board's nuclear-power programme, has made it necessary considerably to extend chemical-processing facilities, and the fabrication of vessels in 18–13–Nb stainless steel is still continuing on a large scale. In this paper the authors report some of the problems encountered in the construction of these vessels, and, in particular, indicate the welding techniques developed to carry out the work to the high quality desired.

The paper is in four sections. In the first, which covers the welding of 18–13–Nb stainless steels for use in plant handling radioactive process liquors, details are given of the controls necessary to ensure freedom from cracking, and the methods used in the production of pipe branch connexions are described.

The second section is concerned with a unique problem, that of 'criticality', confronting the designer of such chemical plant: the problem necessitates careful design to avoid chain reactions when highly enriched materials are involved, and the systems to safeguard against this hazard are discussed in some detail.

The difficulties encountered during the fabrication of components in 'Monel' and 'Inconel' form the subjects of the third section of the paper, the information presented in which indicate that consistency of weld quality in these materials cannot be assured with the same certainty as with stainless steel. Most of the vessels in these materials were fabricated using manual metal-arc techniques, but for pipe work, and for plant in which access for welding was available only from one side, use of argon-arc techniques with appropriate filler wires was found essential.

The data considered in the final section, in which particulars are given of metallurgical studies of corrosion failures which occurred during initial operation of plant manufactured from nickel-containing materials, suggest that, for the particular service conditions, higher corrosion-resistance was obtained when niobium was excluded from the weld metal.

Welding of Martensitic and Semi-Austenitic Precipitation-Hardening Stainless Steels

J. I. MORLEY and J. A. MCWILLIAM: 'Welding of Precipitation-Hardening Corrosion-Resisting Steels.'

Brit. Welding Jnl., 1960, vol. 7, Oct., pp. 651–8.

The demand for high-strength stainless steels which are readily weldable has been met by two types of steel: (*A*) those of low-carbon martensitic type and (*B*) those of semi-austenitic type. Typical compositions (see table on next page) contain chromium, nickel, copper and molybdenum.

Type	C %	Si %	Mn %	Cr %	Ni %	Mo %	Cu %	Nb %
A	0·05	0·35	0·80	15·0	5·5	1·5	1·5	0·3
B	0·05	0·50	1·00	16·0	5·5	2·0	2·0	—

The balance of composition is carefully controlled to ensure ready weldability and the response to heat-treatment required to give the desired mechanical properties. This paper reviews the information available on the metallurgical features and the weldability of the two types of steel in the form of bar, sheet and centri-die-spun castings.

Heat-treatments are discussed, and data are presented typifying physical and mechanical properties. Weldability is reviewed (in terms of the use of the metal-arc-, argon-arc-, inert-gas metal-arc- and resistance-welding processes), and the mechanical properties obtainable in welds, and the influence, in this respect, of post-weld heat-treatments, are considered.

Mechanical Properties of Misaligned Butt-Welds in 'A-286' Steel

D. E. HACKER and S. WEISS: 'Evaluation of Misaligned Butt-Welded 'A-286' and Cr-Mo-V.'

Welding Jnl., 1960, vol. 39, Aug., pp. 797-801.

Inert-gas-shielded tungsten-arc welding is employed extensively in the fabrication of sheet components for gas turbines. Design criteria for the mechanical properties of welded butt-joints in sheet material are, however, generally based on data derived from laboratory-welded specimens produced under ideal conditions with little or no mismatch, and, since it was anticipated that varying degrees of mismatch may occur during the manufacture of large-diameter and complex jet-engine sheet components of advanced design, the investigation described was undertaken to determine the relationship between the degree of misalignment and the mechanical properties of the weld.

Two materials, representative of those used in jet-engine fabrication, were selected for study: (1) a low-alloy chromium-molybdenum-vanadium steel; (2) the nickel-chromium precipitation-hardenable heat-resisting steel 'A-286'. The study was restricted to sheet specimens exhibiting a mismatch of 0, 50 and 100 per cent. (exaggerated conditions of mismatch were used as a means of readily detecting any resultant effects on mechanical properties). The specimens were subjected to fatigue tests, short-time tensile tests at room and elevated temperatures, and short-time stress-rupture tests. The specimens tested were composites, consisting of the reinforced weld, the heat-affected zone and the 0·062-in.-thick base material.

The results of the study demonstrate that severe misalignment substantially lowered the tensile and stress-rupture properties of 'A-286' welded joints. Though the ultimate tensile properties of the welded joints in the chromium-molybdenum-vanadium steel were not affected by severe mismatch, yield properties were lowered. Fatigue properties of welded joints in both materials were considerably reduced. The adverse effect on tensile and rupture properties is believed to be enhanced by the effects of moment forces and increased fibre stresses acting in the mismatch area.

Factors Influencing Fusion-Line Cracking of Welded Cupro-Nickels

See abstract on p. 273.

Development and Properties of High-Temperature Brazing Alloys

W. FEDUSKA: 'New Alloys for Brazing Heat-Resisting Alloys.'

Welding Jnl., 1960, vol. 39, July, pp. 292s-300s.

Most commercial high-temperature brazing alloys are of the following types: (1) nickel-chromium-silicon-boron-carbon alloys, (2) nickel-chromium-silicon alloys, (3) nickel-silicon-boron alloys, (4) nickel-phosphorus alloys, and (5) nickel-phosphorus-chromium alloys. These alloys perform very well in many applications, but may have disadvantages under certain conditions. The investigation reported was undertaken to 'develop a ductile brazing alloy, or alloys, which might possess superior wettability and produce ductile joints with various stainless steels, titanium/aluminium-bearing alloys, or aluminium-iron type alloys, without reacting excessively with these materials'.

Consideration of theories pertinent to wettability and to the development of a ductile brazing alloy (the points considered are referred to in the introductory section of the paper) led to the conclusion that a solid-solution alloy containing nickel, palladium and small concentrations of beryllium and/or silicon would constitute a different type of brazing alloy capable not only of bonding to high-temperature alloys without excessive basis-metal erosion, but also of producing ductile brazed joints and of wetting and adhering to titanium- and/or aluminium-containing alloys. In the investigations that followed this conclusion the properties of nine brazing alloys were evaluated: see compositions in table on p. 292. The following types of material were used as basis metals: chromium-nickel stainless steels (A.I.S.I. Type 304, 316 and 347); a titanium-hardened iron-nickel-chromium-base alloy; a titanium-hardened nickel-chromium-iron-base alloy; a cobalt-nickel-base high-damping alloy; two cast nickel-base alloys; an iron-aluminium alloy; and iron-aluminium-chromium alloys.

The investigation involved the following phases:

(1) Determination of liquid/solidus temperature ranges by means of the cooling-curve technique.

Nominal Compositions of Brazing Alloys Evaluated

(*See abstract p. 291*)

Brazing Alloy	Ni wt. %	Si wt. %	Be wt. %	Cr wt. %	Pd wt. %	Estimated per cent. Solid Solution in Microstructure
1	40·0 (40·1)*	0·5 (0·46)	—	—	59·5	95-97
2	39·5	1·5 (1·40)	—	—	59·0	90
3	38·5	3·0	—	—	58·5	40
4	40·0 (40·7)	—	0·25 (0·30)	—	59·75	93-95
5	40·0 (41·1)	—	0·5 (0·66)	—	59·5	90
6	40·0 (41·7)	—	1·0 (1·15)	—	59·0	50
7	35·84	0·25	0·15	10·0	53·76	90-95
8	29·0	—	—	28·0	43·0	100
9	40·0 (44·3)	0·50 (0·49)	0·25 (0·25)	—	59·25 (54·96)	90-95

* Actual compositions in parentheses.

(2) Determination of microstructures and microhardness.

(3) Study of the degree to which the most promising alloys were workable into strip stock.

(4) Wettability tests (using various basis materials) and determination of wetting-index data.

(5) Bend tests on, and determination of the shear-strength of, lap-joint specimens brazed using, as basis materials, 18-8 or 18-8-Mo stainless steels or various nickel-base high-temperature alloys.

(6) Elevated-temperature shear tests on double-lap joints produced from a cast nickel-base high-temperature alloy using Brazing Alloy 9.

(7) Determination of the structure and microhardness of brazed-joint interfaces.

The results obtained in the different phases of the study are discussed by the author in separate sections. The most promising of the alloys evaluated was found to be Alloy 9. This alloy has a melting temperature range of 2040°-2120°F. (1115°-1160°C.), is workable into thin strip stock, exhibits superior wettability in relation to titanium- and/or aluminium-bearing high-temperature alloys, causes little basis-metal penetration or erosion during brazing of thin-walled wrought materials, and has adequate shear strength at temperatures up to 1500°F. and satisfactory ductility at room temperature: *see data on double lap joints brazed in a cast nickel-chromium-cobalt-base alloy tabulated in right-hand column.*

The beryllium and/or silicon contents of the brazing alloys studied result, in the presence of palladium and nickel, in lower melting compositions during reactions with basis steels of A.I.S.I. 304 and 316 type, an effect which enables these materials to be brazed, with little basis-metal grain coarsening or erosion, at temperatures in the range 1920°-1985°F. (1045°-1080°C.).

Test Temperature		Average Ultimate Shear Strength		
°F.	°C.	t.s.i.	p.s.i.	kg./mm.²
1000	540	20·5	46,400	32·5
1500	815	9·0	20,600	14·5
1800	980	2·0	4,800	3·5

High-Frequency Induction Brazing of Stainless Steel

P. M. BARTLE and J. G. YOUNG: 'High-Frequency Induction Brazing of Small Components in Argon Streams.'

Brit. Welding Jnl., 1960, vol. 7, Oct., pp. 638-42.

High-frequency induction brazing in argon streams has been suggested as a valuable technique for joining small components in similar or dissimilar metals. The technique requires the minimum of operational skill, and, with a little experience, can be as easily employed for one-off jobs as for production runs. No flux is used, and, since protection is by external streams of argon, the time involved is reduced to a minimum. In the course of a recently completed contract, the British Welding Research Association successfully applied this technique to a batch of components requiring a very high standard of joint leak-tightness. It was considered that the experience gained on a particular combination of metals could be readily extended to other materials, and, with this aim in mind, the present authors report the results of a preliminary study of the use of the

technique in joining certain similar and dissimilar metals.

The tube-to-plate assembly was the basic type of joint chosen to evaluate the materials studied (titanium sheet; nickel-stabilized 18-8 stainless-steel sheet and tube; copper, mild-steel and stabilized and unstabilized stainless-steel tube).

Provided that the parent materials were non-film-forming, no difficulty was encountered in finding suitable filler materials for this type of induction brazing. Satisfactory joints, though possible, were less easy to make when stainless steel was included in the combination, but, contrary to general belief, the titanium-stabilized grade of stainless steel did not involve greater wetting problems than the unstabilized steel, and strength tests indicated that good joint production was perhaps slightly easier than with the unstabilized steel. The difference in the behaviour of various filler in joints between stainless-steel tubes and titanium or stainless-steel plate materials is considered a significant feature of the results obtained from the wetting tests. Wetting of the stainless-steel tube was improved as a result of solution of titanium in the filler alloy. Nickel plating the stainless steel prior to brazing was found to be beneficial, permitting the use of filler that otherwise would not have wetted the steel or would have required considerable superheat.

A.W.S./A.S.T.M. Chemical Requirements for Hardfacing Electrodes

'Chemical Requirements for Hardfacing Electrodes, Rods.'

Welding Engineer, 1960, vol. 45, Mid-June, pp. 22-23.

Compositional requirements relevant to the various A.W.S./A.S.T.M. classifications covering hardfacing electrodes or rods of iron, cobalt, copper or nickel base are tabulated in ready-reference form.

ANALYSIS

Spectrographic Determination of Impurities in High-Purity Nickel Powder

See abstract on p. 271.

Spectrographic Analysis of High-Purity Nickel

See abstract on p. 271.

Determination of Chromium in Nickel-containing Steels

See abstract on p. 278.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Trade Marks*.

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